CHAPTER II
MECHANICAL PROPERTIES OF MATERIAL

Materials are selected for different applications and components according to their properties and adapting them to the functional conditions of the component. The first step in the selection process requires the analysis of the application to determine the main characteristics that the material must have. Once established, the properties that the application requires we can go to the manuals and search for the material that accomplish with the required properties. However, it is also important to know how these properties are obtained and to obtain them in some cases, since we know that the results from ideal tests can not be applied exactly to real engineering cases.

2.1 Hardness

It is defined as hardness the resistance of a material to be permanently deformed, also can be expressed as the opposition of the material to be penetrated. The hardness of a material depends on several physical factors and there are different methods to evaluate it and each one of them uses different parameters in consideration. The most popular are three: [93]

a) Elastic Hardness:

   This kind of hardness is measured by a scleroscope (Fig. 2.1). This is a device designed to measure the height of the bounce of a little diamond hammer after it falls by its own weigh from a certain height on the surface of the tested sample.

This instrument usually has an auto indicator disc such that registers automatically the height of the bounce. Higher bounce indicates that the sample is harder. This test really is a measure of the energy that the material is able to absorb in the elastic range.

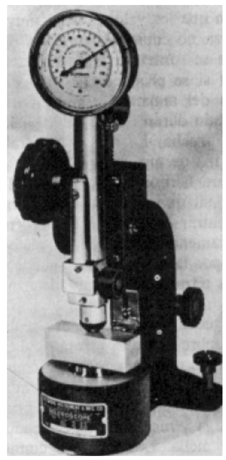

Fig. 2.1. Scleroscope for elastic hardness test

b) Cut or Abrasion Resistance

Scratch test: This test consists of a scale of 10 standard minerals arranged in ascending scale of hardness. Talc is 1, plaster is 2, etc up to 9 for corundum and 10 for diamond. If the tested material is substantially scratched by mineral number 6, but not by number 5, the hardness of this material is between 5 and 6. This test is not very used in metallurgy but it is still used in mineralogy.

The principal disadvantage is that this scale is not uniform because when the hardness of these minerals were tested by other method, it was found that the values between 1 and 9 were very close and there is a huge difference of non covered hardness between 9 and 10.

File test: The tested sample is subjected to the cut of a file with a known hardness, to determine if it produces a visible cut. The comparative tests with a file depend of the size, shape and hardness of the file and of the speed, pressure and angle of the file during the test and of the composition, thermal treatment of the tested material.

c) Penetration Test

This test is usually made by making indentation in the sample, which is resting over a rigid platform, using an indentator of a determined geometry, under a static known load that is applied directly or by a lever system. According to the test system, the hardness is expressed by a number inversely proportional to the depth of the penetration for a specified charge and indentator. The most common methods of hardness penetration tests are:

i. Brinell Hardness Test

This test generally consists in a hydraulic vertical press of manual operation, designed to force a ball indentator into the sample.

The standard procedure requires the test to be done with a 10 mm diameter ball under a 3000 Kg load for ferrous materials and 500 for non ferrous materials. For ferrous materials, the ball under force is pressed into the tested sample for al least 10 sec; for non ferrous materials the time is of 30 sec. The diameter of the printed hole is measured with a microscope with an ocular scale gauged every 1/10mm that allows estimations of up to 0.05 mm.

The value of the Brinell Hardness is calculated by the formula 1.1:

Formula 1.1 $$HB = \frac{L}{(\pi D/2)(D-(D^2-d^2)^{1/2})}$$

Where:

L = Load, Kg.

D = Diameter of the ball, mm.

D = Diameter of the print, mm.

ii. Rockwell Hardness Test

For this test, it is used a direct reading device, based in the principle of measure of differential depth, Fig 2.2, this test is performed by elevate the sample slowly against the indentator until a minor determinate load has been applied. Then a higher load is applied through a load lever system. After the needle of the disc stops, the higher load go off and with the minor load still applied the number of Rockwell hardness is read. A shallow print in a hard material will show a high number of hardness and a deep print in a soft material will show a low number.

Fig. 2.2. Hardness Rockwell device

Different indentators and loads can be applied, and each combination determines a specific Rockwell scale. Indentators can be steel balls of 1/16, 1/8, 1/4 and 1/2 in. of diameter and a conical diamond indentator of 120^{o}. The high loads are of 60, 100 and 150 Kg in the normal test, while in the shallow test are used 15, 30 and 45 Kg.

The most common Rockwell scales are B (ball of 1/16 in and 100 Kg load) and C (diamond indentator and 150 Kg load), both obtained with the regular test. Because of the many Rockwell scales the value must be specified by the symbol HR followed with the letter that designs the scale. Table 2.1 shows the typical applications and Rockwell scales.

Table 2.1. Rockwell scales and applications

SCALE	LOAD (kg)	INDENTATOR	MATERIALS
A	60	Diamond cone	Extremely hard materials, CW, etc
B	100	Ball 1/16	Medium hard materials, low and medium hardness steels, brass, bronze, etc
C	150	Diamond cone	Hardened steels and alloys
D	100	Diamond cone	Superficially cemented steel
E	100	Ball 1/8	Cast Iron, Al and Mg alloys
F	60	Ball 1/16	Bonze and cooper
G	150	Ball 1/16	Cooper and Phosphorous bronze
H	60	Ball 1/8	Al plate
K	150	Ball 1/8	Cast iron, Al alloys
L	60	Ball 1/4	Plastics and soft materials, as lead
M	100	Ball 1/4	Plastics and soft materials, as lead
P	150	Ball 1/4	Plastics and soft materials, as lead
R	60	Ball 1/2	Plastics and soft materials, as lead
S	100	Ball 1/2	Plastics and soft materials, as lead
V	150	Ball 1/2	Plastics and soft materials, as lead

iii. Vickers Hardness Test

For this test, a square base pyramidal diamond indentator is used of a 136^o between opposite loads, Fig 2.3, the interval of load is generally between 1 and 120 Kg. Vickers hardness test works under the same principle as Brinell does, and the numbers are expressed in terms of load and printing area. As a result of the shape of the indentator, the print over the surface of the sample will be a square, the diagonal length of the square is measured with an ocular micrometer with mobile sharps. The distance between edges is pointed out in a calibrated counter. The hardness value is obtained by the formula 1.2:

Formula 1.2 $$HV = \frac{1.854\ L}{d^2}$$

where:

L = Load, kg.

D = length of the square diagonal of the print

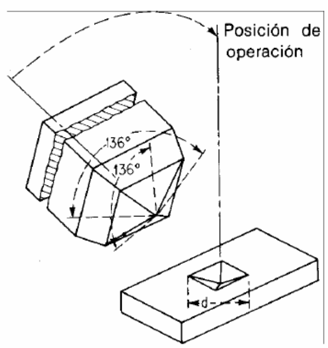

Fig. 2.3. Pyramidal indentator of Vickers diamond

2.1.1. Test

The sample for this test was a vitallium hip prosthesis, provided by a supplier in Puebla, it is shown in fig. 2.4.

Fig. 2.4. Hip prosthesis provided by the supplier

For this study a penetration test was performed, and specifically used the Rockwell C scale because of the characteristics of the sample, it is a hardened alloy, so the machine was prepared with 150 Kg. load and the cone diamond indentator. 5 penetrations were made in the sample and the results of this test were:

Penetration #1 = 37 Rockwell C

Penetration #2 = 35 Rockwell C

Penetration #3 = 36 Rockwell C

Penetration #4 = 37 Rockwell C

Penetration #5 = 36 Rockwell C

Average material hardness = 36.2 Rockwell C

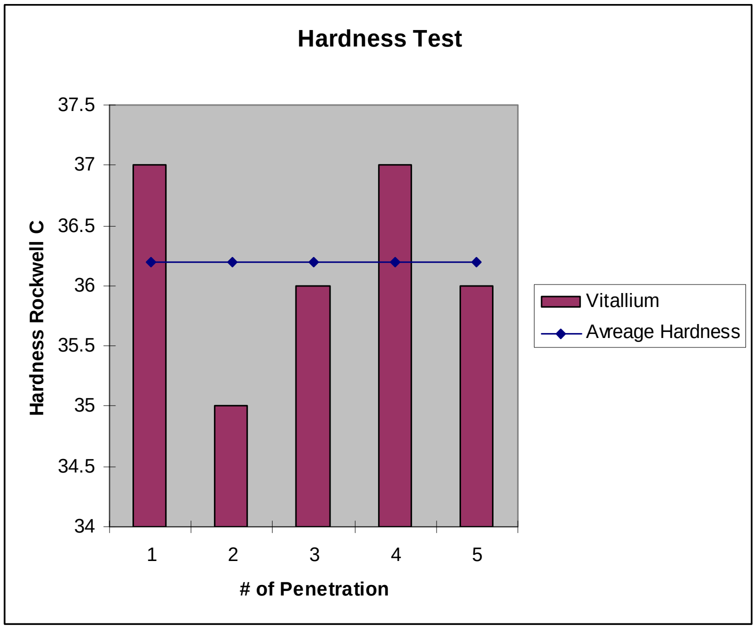

Fig 2.5. Hardness Test Chart

2.2. Impact

The property of a material to absorb energy is designed as tenacity; this is a relation to the required work to produce a fracture in the material; this depends basically on the resistance and ductility of the material and seems to be independent of the type of load. At ambient temperatures, a simple bar of a ductile material won't fracture under an impact flexion load; this is why to induce the fracture of the material whit only one hit, a groove is machined in the sample.

The ideal impact test would be the one where all the energy would be transmitted to the sample in one hit; in reality, this ideal is never archived, there are always some energy lost because of friction or vibration in the impact machine. An impact test can be performed in flexion, tension, compression or torsion.

The most common impact tests are Charpy and Izod, both use the pendulum principle. These tests are performed with grooved samples broken in flexion. The differences between these two test methods are the fixation of the sample and the velocity of the impact; for the Charpy test the model is fixed as a simple beam at a velocity of 17.5 ft/s, while in the Izod test, the sample is fixed as a projection, with only one side fixed at 11.5ft/s. [92]

2.2.1 Test

The firs step is to place the sample in the machine; the groove must point on the contrary to the side that will receive the impact. Then the pendulum is elevated 135°. Theoretically, if there were no sample in the path of the pendulum, it will reach the 135° at the other side if there where no friction or vibration in the machine; but, with the sample placed at the middle some of the energy will be absorbed by the sample reducing the final angle of the pendulum.

To calculate the energy that the sample absorbs the equation used is shown in formula 1.3:

Formula 1.3 $$E = W^{x} R^{x} (\cos\beta - \cos\alpha)$$

Where:

E = energy absorbed by the sample, N ^{x}m

W = Weight of the pendulum, N.

R = Radius of spin of the pendulum, m.

α = Initial angle, ^{o}

β = Final angle, ^{o}

2.2.2. Results

The sample used for this test was obtained from a femur prosthesis provided by a supplier in Puebla; it was machined to obtain an impact test standard sample shown in fig 2.6. Plan of the piece shown in Appendix A.

Fig. 2.6. Impact test standard sample.

The sample is a 6.2 x 6.2 mm of cross section area and 58mm length of cobalt-chromium-molybdenum, commercially called vitallium. It has a 2mm depth groove of 45^{o} and

0.2mm of radius. The pendulum hit the center of the sample, in the opposite face of the groove.

Data:

$W = 26.105$ Kg * $9.81\ m/s^2 = 256.09$ N

$R = 0.75$ m.

$\alpha = 135^o$.

$\beta = 108^o$.

From formula 1.3:

$E = (256.09N) * (0.75m) * (\cos 108^o - \cos 135^o) =$ **76.46 N m**

Energy absorbed = 76.46 N ^{x} m.

The impact did not break the simple but it shows a fracture along the groove.

2.3 Fatigue

In order to perform a fatigue test to a screw it is needed to follow the ASTM standard: F2193 – 02. Standard Specifications and Test Methods for Components used in the Surgical Fixation of the Spinal Skeletal System. [94]

This standard in the summary of method indicates that:

> “Samples of a given spinal screw are loaded under cantilever bending in a sinusoidal cyclic manner at a predetermined frequency. The fatigue loading is continued until the specimen fails, a limit is reached which terminates the test, or until a predetermined cycle count (round limit) is reached. “

This test method assumes that the spinal screws are manufactured from a material that exhibits linear – elastic range and restricted to the testing of spinal screws within the materials elastic range.

2.3.1 System requirements

To perform a fatigue test it is needed to have in good shape:

a. Force transducer. A calibrated sensor capable of measuring dynamic loads.
b. Cycle counter. A device capable of counting the number of loading cycles applied to the sample.
c. Limit. A device capable of detecting when a test parameter reaches a limit value, at which time the test is stopped and the cycle counting is maintained.

2.3.2 Fixture requirements.

Any test fixture implemented shall be sufficiently rigid so that its deformation under the maximum load is less than 1% the test sample’s deformation. Also the threaded region of the spinal screw must be embedded into a test block made from a synthetic material that is easily processed with standard spinal fixation system instruments recommended a stainless steel at 40 HRC minimum.

An anchoring fixture is rigidly attached to the spinal screw's head so that the screw's head is fully constrained during the test. The load is applied to the test sample at the end containing the test block, which is protected from localized failure by a protection sleeve placed around the test block. As shown in Fig 2.7.

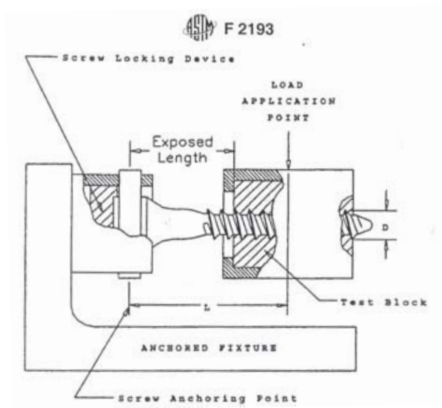

Fig. 2.7. Spinal screw test configuration fixture.

2.3.3. Sampling

Only unused and untested specimens must be included in the sample for a given spinal component design. At least two specimens at each of three different maximum moment levels are required to be tested. One of the three maximum levels should satisfy the maximum run out moment condition. The samples used, must have sufficient length in order to have at least 5 mm of screw thread included in the exposed length.

2.3.4. Procedure

The procedure for a fatigue test method recommended by ASTM looks as follows:

a. Conduct the recommended fatigue test in a laboratory air environment at room temperature. If an alternative test environment is used, record all pertinent parameters related to the environmental conditions before, during and after the test.
b. Apply sinusoidal cyclic loads in load control at an R ratio of 0.1 for testing devices intender for either the lumbar or thoracic spine regions and sinusoidal cyclic loads in load control at an R ratio of -1.0 for testing of devices intended for the cervical spine region. Other R ratios may be used but must be documented.
c. The user will determine the frequency at which to conduct the fatigue test. The maximum recommended frequency of cyclic loading is 30 Hz.
d. Initial fatigue maximum moment levels that are 75, 50, and 25% of the bending ultimate moment determined with the static stress method are suggested for the fatigue study. One maximum moment level should have specimens that do not fail before 2 500 000 cycles. The difference between the maximum moment value resulting in specimen failure and the maximum run out moment value must be less that 10% of the device’s bending ultimate moment.
e. The cycle counter must record a cumulative number of cycles applied to the test specimen, and the appropriate limits should be set to indicate specimen failure.
f. Testing must continue until the specimen breaks.
g. Record the results of each test including the maximum moment, cycle count at test termination and failure location and failure mode.

2.3.5. Experimental Results

Since the facilities, resources and samples did not coincide in order to perform a satisfactory fatigue test. The experimental results obtained in an article by Harvey Smith, titled “Cervical Arthoplasty: Material Properties” published in Neurosurg Focus in September 2004 shows the following fatigue test and results.

This publication does not explains in detail the conditions of this test, but it does says that was applied a repetitive axial load as applied to samples of 6.35 mm gage diameter, and the results are shown in figure 2.8.

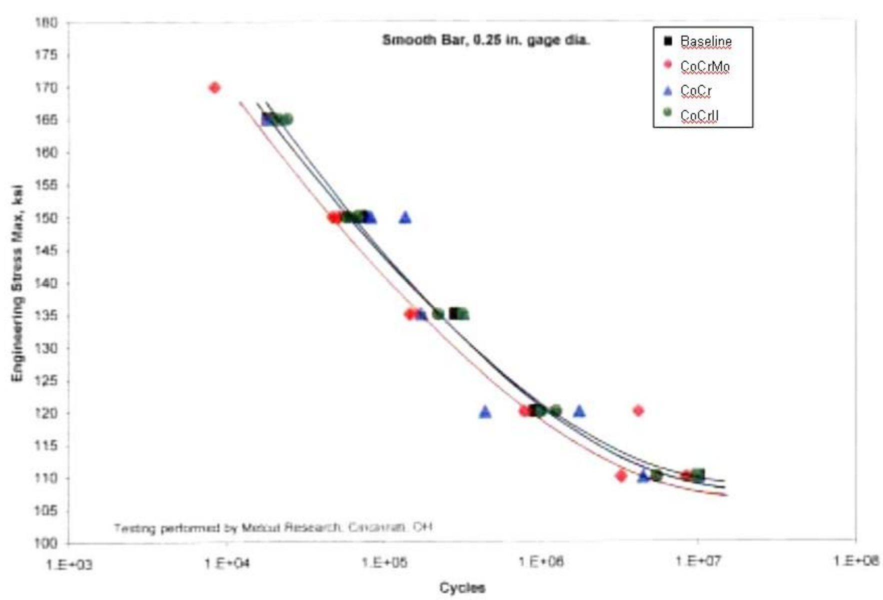

Fig 2.8 Axial Fatigue Results in cervical implants